JC04 Rec'd PCT/PTO 15 JUN 2001

FORM PTO-1390 US DEPARTMENT OF COMMERCE REV. 5-93PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEYS DOCKET NUMBER **P01,0184** U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/868239
INTERNATIONAL APPLICATION NO. **PCT/DE99/03955**	INTERNATIONAL FILING DATE **10 DECEMBER 1999**	PRIORITY DATE CLAIMED **16 DECEMBER 1998**
TITLE OF INVENTION **METHOD AND ARRANGEMENT FOR PREDICTING MEASUREMENT DATA USING GIVEN MEASUREMENT DATA**		
APPLICANT(S) FOR DO/EO/US **THOMAS ACKERMANN ET AL.**		

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay.

4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. ☒ A copy of International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)

6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2).

7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. §371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.

8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)) - **UNSIGNED**.

10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98; **(PTO 1449, Prior Art, Search Report, References)**.

12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included. **(SEE ATTACHED ENVELOPE)**

13. ☒ Amendment "A" Prior to Action and Appendix "A".
    ☐ A SECOND or SUBSEQUENT preliminary amendment.

14. ☒ A substitute specification and mark-up for substitute specification.

15. ☐ A change of address letter attached to the Declaration.

16. ☒ Other items or information:

    a. ☒ Submission of Drawings, 4 sheets of drawings, Figures 1-5.

    b. ☒ EXPRESS MAIL #EL 843728773 US dated June 15, 2001.

JC18 Rec'd PCT/PTO 15 JUN 2001

U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5) 09/868239	INTERNATIONAL APPLICATION NO PCT/DE99/03955	ATTORNEY'S DOCKET NUMBER P01,0184

				CALCULATIONS	PTO USE ONLY
17. ☒ The following fees are submitted: **BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):** Search Report has been prepared by the EPO or JPO $860 00 International preliminary examination fee paid to USPTO (37 C F.R. 1 482) $690 00 No international preliminary examination fee paid to USPTO (37 C.F.R. 1.482) but international search fee paid to USPTO (37 C F.R. 1.445(a)(2) $710.00 Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2) paid to USPTO $1000.00 International preliminary examination fee paid to USPTO (37 C F.R 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $ 100.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	09 - 20 =	0	X $ 18.00	$	
Independent Claims	04 - 3 =	1	X $ 80.00	$ 80.00	
Multiple Dependent Claims			$270.00 +	$	
TOTAL OF ABOVE CALCULATIONS =				$ 940.00	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed (Note 37 C.F.R. 1.9, 1.27, 1.28)				$	
SUBTOTAL =				$ 940.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)) +				$	
TOTAL NATIONAL FEE =				$ 940.00	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R 3.28, 3.31). $40.00 per property +					
TOTAL FEES ENCLOSED =				$ 940.00	
				Amount to be refunded	$
				charged	$

a. ☒ A check in the amount of $ 940.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ________ in the amount of $ ______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 50-1519. **A duplicate copy of this sheet is enclosed.**

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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JC18 Rec'd PCT/PTO 15 JUN 2001

BOX PCT
IN THE UNITED STATES DESIGNATED/ELECTED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY--CHAPTER II

PRELIMINARY AMENDMENT A
PRIOR TO ACTION

APPLICANT(S):	Thomas ACKERMANN et al
ATTORNEY DOCKET NO.:	P01,0184
INTERNATIONAL APPLICATION NO:	PCT/DE99/03955
INTERNATIONAL FILING DATE:	10 December 1999

INVENTION: METHOD AND ARRANGEMENT FOR PREDICTING MEASUREMENT DATA USING GIVEN MEASUREMENT DATA

Assistant Commissioner for Patents,
Washington D.C. 20231

Sir:

Applicants herewith amend the above-referenced PCT application, and request entry of the Amendment prior to examination on the United States Examination Phase.

IN THE CLAIMS:

On page 20:

replace line 1 with --WHAT IS CLAIMED IS:--;

Please replace original claims 1-9 with the following rewritten claims 1-9, referring to the mark-ups in Appendix A.

1. (Amended) A method for predicting measurement data until a final time-point using given measurement data, comprising the steps of:

a) matching, using a processor, a stochastic process to said given measurement data;

b) running simulation runs of said stochastic process from a given time-point until said final time-point;

c) determining forecast measurement data for each simulation run; and

d) predicting measurement data by stating a range of values, which is determined by said forecast measurement data, and providing said predicted measurement data as useable output.

2. (Amended) The method as claimed in claim 1, further comprising the steps of:

determining a confidence range for said prediction of measurement data; and

eliminating a% lowest and b% highest forecast measurement data.

3. (Amended) The method as claimed in claim 2, wherein a% and b% are equal values.

4. (Amended) The method as claimed in claim 1, wherein said stochastic process is a non-homogeneous Poisson process.

5. (Amended) The method as claimed in claim 1, wherein said measurement data represents numbers of errors.

6. (Amended) A method for predicting measurement data using given measurement data, comprising the steps of:

a) matching, using a processor, a stochastic process to said given measurement data;

b) sorting probability values generated by said stochastic process according to size, to provide a range around an expected value; and

c) predicting measurement data within limits of said range, and providing said predicted measurement data as useable output.

7. (Amended) The method as claimed in claim 6, further comprising the steps of:

sorting said probability values generated by said stochastic process symmetrically by size around said expected value.

8. (Amended) An arrangement for predicting measurement data until a final time-point using given measurement data, comprising:

a processor unit, having a CPU, bus, memory, and input/output controller, configured in such a way that:

a) a stochastic process can be matched to said given measurement data;

b) simulation runs of the stochastic process can be carried out from a given time-point until the final time-point;

c) forecast measurement data can be determined for each simulation run; and

d) measurement data is predicted by stating a range of values, which is determined by said forecast measurement data, said measurement data being output in a useable form.

9. (Amended) An arrangement for predicting measurement data using given measurement data, comprising:

a processor unit, having a CPU, bus, memory, and input/output controller, configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) a range can be ascertained by sorting probability values generated by said stochastic process according to size around an expected value; and

c) said measurement data is predicted within the limits of the range, said measurement data being output in useable form.

REMARKS

The present Amendment revises the specification and claims to conform to United States patent practice, before examination of the present PCT application in the United States National Examination Phase. Pursuant to 37 CFR 1.125 (b), applicants have concurrently submitted a substitute specification, excluding the claims, and provided a marked-up copy. All of the changes are editorial and applicant believes no new matter is added thereby. The amendment, addition, and/or cancellation of claims is not intended to be a surrender of any of the subject matter of those claims.

Early examination on the merits is respectfully requested.

Submitted by,

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Appendix A
Mark Ups for Claim Amendments

1. **(Amended)** A method for predicting measurement data until a final time-point using given measurement data, [~~in which~~]**comprising the steps of**:

a) **matching, using a processor,** a stochastic process [~~is matched~~]to [~~the~~]**said** given measurement data;

b) **running** simulation runs of [~~the~~]**said** stochastic process[~~ are carried out~~] from a given time-point until [~~the~~]**said** final time-point;

c) [~~the~~]**determining** forecast measurement data[~~ is determined~~] for each simulation run;**and**

d) **predicting** measurement data[~~ is predicted~~] by stating a range of values, which is determined by [~~the~~]**said** forecast measurement data**, and providing said predicted measurement data as useable output**.

2. **(Amended)** The method as claimed in claim 1, [~~in which~~]**further comprising the steps of**:

determining a confidence range [~~is determined~~]for [~~the~~]**said** prediction of measurement data[~~, where the~~]**; and**

eliminating a% lowest and b% highest forecast measurement data[~~are eliminated~~].

3. **(Amended)** The method as claimed in claim 2, [~~in~~]**wherein** [~~which:~~]a% and b% are equal **values**.

4. **(Amended)** The method as claimed in [~~one of the preceding claims, in which:~~][~~the~~]**claim 1, wherein said** stochastic process is a non-homogeneous Poisson process.

5. **(Amended)** The method as claimed in [~~one of the preceding claims, in which:~~][~~the~~]**claim 1, wherein said** measurement data represents numbers of errors.

6. [~~The~~]**(Amended) A** method for predicting measurement data using given measurement data, [~~in which~~]**comprising the steps of**:

a) **matching, using a processor,** a stochastic process [~~is matched~~]to [~~the~~]**said** given measurement data;

b) [~~a range is ascertained, by~~]sorting [~~the~~]probability values generated by [~~the~~]**said** stochastic process according to size, **to provide a range** around an expected value;**and**

c) **predicting** measurement data[~~ is predicted~~] within [~~the~~]limits of [~~the~~]**said** range**, and providing said predicted measurement data as useable output**.

7. **(Amended)** The method as claimed in claim 6, [~~in which~~]**further comprising the steps of**:

[~~the~~]**sorting said** probability values generated by [~~the~~]**said** stochastic process[~~ are sorted~~] symmetrically by size around [~~the~~]**said** expected value.

8. **(Amended)** An arrangement for predicting measurement data until a final time-point using given measurement data, [~~whereby~~]**comprising:**

a processor unit[~~ is provided and~~]**, having a CPU, bus, memory, and input/output controller,** configured in such a way that:

a) a stochastic process can be matched to [~~the~~]**said** given measurement data;

b) simulation runs of the stochastic process can be carried out from a given time-point until the final time-point;

c) [~~the~~]forecast measurement data can be determined for each simulation run;**and**

d) measurement data is predicted by stating a range of values, which is determined by [~~the~~]**said** forecast measurement data**, said measurement data being output in a useable form**.

9. **(Amended)** An arrangement for predicting measurement data using given measurement data, [~~whereby~~]**comprising:**

a processor unit[~~ is provided and~~]**, having a CPU, bus, memory, and input/output controller,** configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) a range can be ascertained by sorting probability values generated by [~~the~~]**said** stochastic process according to size around an expected value;**and**

c) [~~the~~]**said** measurement data is predicted within the limits of the range**, said measurement data being output in useable form**.

SPECIFICATION

TITLE

METHOD AND ARRANGEMENT FOR PREDICTING MEASUREMENT DATA USING GIVEN MEASUREMENT DATA

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates to a method and arrangement for predicting measurement data using given measurement data.

Description of the Related Art

[0002] A technical system often requires facilities for forecasting based on known (measurement) data, particularly in the context of error susceptibility or cost estimates.

[0003] Forecasts generated by experts are generally subject to errors. Experts cannot carry out exact analyses, at least of highly complex systems.

[0004] A stochastic point process, in particular a Poisson process, is described in Sidney I. Resnick: "Adventures in Stochastic Processes", Birkhäuser Boston, 1992, ISBN 3-7643-3591-2, pp. 303-317 (Resnick).

Summary of the Invention

[0005] The object of the invention is to allow the automatic prediction (forecast) of measurement data using given measurement data.

[0006] This object is achieved in accordance with the method and apparatus described below; developments of the invention are also described in the following text.

[0007] In order to achieve this object, a method is provided for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. Simulation runs are carried out from a given time-point until a final time-point. The forecast measurement data is determined for each simulation run. Measurement data for the final time-point is

predicted within a range of values, which is governed by the forecast measurement data.

[0008] One development is to define a confidence range for the prediction of measurement data, where the a% lowest and b% highest forecast measurement data are eliminated. In particular, a% can equal b%. For example, a 95% confidence range can thus be defined by ignoring the 2.5% lowest and 2.5% highest forecast measurement data.

[0009] One advantage is that the measurement data can be predicted (forecast) with an accuracy that is within a confidence range, from a given time-point. This makes it possible to identify, e.g., the feasibility or impossibility of a task associated with the measurement data, at an early stage. Appropriate measures can therefore be initiated in order to counteract forecast impossibility.

[0010] This is particularly important in the case of a complex system, e.g., a software development process, where the extent to which a schedule can be followed before the software is completed can be shown in a subsequent test phase. Even more important in this context is the ability to adopt countermeasures at an early stage if a delay has been clearly identified, e.g., in an integration test phase. This firstly affects the feasibility of the specified deadline (timescale) and secondly directly affects costs, since non-compliance with the agreed timescale often results in additional costs.

[0011] One refinement is for the stochastic process to be a non-homogeneous Poisson process.

[0012] In particular, the measurement data may in one refinement comprise numbers of errors. This applies to software development, for example, where the level of maturity is documented in accordance with the errors measured in a test phase. Completion is directly dependent on this level of maturity. In other words, the software cannot be delivered to customers until most of the errors have been removed from the software. This is particularly important with regard to resources (required to test and correct errors) and costs (due to delayed delivery).

[0013] In order to achieve the object of the invention, a method is also provided for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. A range is

ascertained, by sorting the probability values generated by the stochastic process according to size, around an expected value. Measurement data is predicted on the basis of this range, and in particular the probability values within the range.

[0014] One development is for the probability values generated by the stochastic process to be sorted symmetrically by size around the expected value. In particular, this means that the highest probability value represents the middle of the range, i.e., the expected value, whereas the next highest probability value is arranged to the right or left of the expected value. The next highest probability value is then arranged symmetrically on the other side of the expected value, in turn.

[0015] This analytical (design) procedure provides a range, where the breadth of the range in turn indicates which probability values are significant in the prediction of the measurement data.

[0016] In one particular refinement, the breadth of the range is determined by ignoring the probability values that lie below a given threshold.

[0017] This produces a range (confidence range), which has a specific breadth as a result of the threshold. This breadth corresponds to the certainty with which the measurement data is predicted.

[0018] If one assumes that the stochastic process is a non-homogeneous Poisson process, then the non-homogeneous Poisson process defines a step size, particularly on a time axis t, which indicates when the next error will occur. One characteristic of the non-homogeneous Poisson process is that it has no memory, so that a "no-memory" search is carried out from each error that occurs at a specific time-point, for a time-point that indicates the next error.

[0019] In order to achieve the object of the invention, an arrangement is also provided for predicting measurement data using given measurement data that has a processor unit and is configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) simulation runs can be carried out from a given time-point until a final time-point;

c) the forecast measurement data can be determined for each simulation run; and

d) the prediction of measurement data for the final time-point can be predicted within a range of values, which is determined by the forecast measurement data.

[0020] In order to achieve the object of the invention, an arrangement is further provided for predicting measurement data using given measurement data that has a processor unit and is configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) a range can be ascertained by sorting probability values generated by the stochastic process according to size around an expected value; and

c) the measurement data is predicted within the limits of the range.

[0021] The arrangements are particularly suitable for carrying out the inventive method or the developments described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Exemplary embodiments of the invention are shown and explained below with reference to the drawings, in which:

Fig. 1 is a graph showing an accumulated number of errors over a test period;

Fig. 2 is a graph showing the superimposed confidence ranges for different process models;

Fig. 3 is a flowchart showing the steps in a method for predicting measurement data using given measurement data;

Fig. 4 is a further flowchart showing the steps in a method for predicting measurement data using given measurement data; and

Fig. 5 is a block diagram showing a processor unit.

DETAILED DESCRIPTION OF THE INVENTION

[0023] In order to be able to forecast a number of expected errors in a technical process, e.g., in a software development process, non-homogeneous Poisson processes (NHPP) are calibrated (i.e., matched to measurement data, such as the occurrence of errors over time) as follows:

[0024] The following equation describes a counting process associated with the stochastic point process (non-homogeneous Poisson process):

[0025] $$\{N(t)\}_{t \in \mathbf{R}^+} \qquad (1)$$

[0026] and a time-point t_0 defines the end of a test period, i.e., a time-point at which the given data ends. The stochastic processes

$$\{U(t)\}_{t \in \mathbf{R}^+} \quad \text{and} \qquad (2)$$

[0027] $$\{O(t)\}_{t \in \mathbf{R}^+} \qquad (3)$$

[0028] are searched with

[0029] $$P\big(U(t) \le N(t) - N(t_0) \le O(t) \,\big|\, N(t_0) = n_0\big) \ge \alpha \qquad (4),$$

[0030] for all time-points where t>t0 and given values $\alpha \in (0.1)$ (confidence level) and n0 $\in$ N. In particular, the following text examines the increases in the stochastic countings process in relation to the time-point t_0.

[0031] In the present case, where equation (1) represents a non-homogeneous Poisson process, the following equation (cf. Resnick)

[0032] $$P\big(N(t_1) - N(t_0) = \ell\big) = \exp\big(-[i(t_1) - i(t_0)]\big) \cdot \frac{[i(t_1) - i(t_0)]^{\ell}}{\ell\,!} \qquad (5)$$

[0033] applies for

[0034] $$0 \le t_0 < t_1 < \infty, \quad \ell \in \mathbf{N}_0 \qquad (6)$$

[0035] and an intensity (mean measure, mean value function) of

[0036]

$$i: \mathbf{R}^+ \to \mathbf{R}^+, t \mapsto i(t) := EN(t) \qquad (7).$$

[0037] Since the nature of the Poisson process dictates that the increases (error increases in this case) are independent of previous increases, equation (5) for the time-points t>t_0 to define a (minimum) range

[0038] $$[g_u, g_o] \equiv [g_u(t), g_o(t)] \subset \mathbf{N}_0 \qquad (8)$$

[0039] can be simplified to

[0040] $$\sum_{\ell=g_u}^{g_o} P\left(N(t) - N(t_0) = \ell\right) \geq \alpha \qquad (9).$$

[0041] Due to the unimodal nature of the Poisson count density, a range $[g_u, g_o]$ can be determined as follows:

[0042] Step 1: Sort the elementary probabilities

[0043] $$p_\ell := P\left(N(t) - N(t_0) = \ell\right),\ \ell \in \mathbf{N}_0$$

[0044] into descending order and label the values sorted thus using

[0045] $$P(0), P(1), \ldots \qquad (\text{i.e. } \{p_0, p_1, \ldots\} = \{P(0), P(1), \ldots\} \text{ and } P(0) \geq P(1) \geq \ldots);$$

[0046] Step 2: Determine $\ell_{min} := \min\left\{\ell \in \mathbf{N}_0 \,\middle|\, \sum_{i=0}^{\ell} P(i) \geq \alpha\right\};$;

[0047] Step 3: Determine an index set

[0048] $$I := \{i_0, \ldots, i_{\ell_{min}}\} \subset \mathbf{N}_0 \quad \text{where}$$

[0049] $$\{p_{i_0}, \ldots, p_{i_{\ell_{min}}}\} = \{P(0), \ldots, P(\ell_{min})\};$$

[0050] Step 4: Substitute $g_u := \min_{i \in I}\{i\}$ and $g_o := \max_{i \in I}\{i\}$.

[0051] The range from equation (8) is also referred to as the forecast range.

Stochastic simulation (second approach)

[0052] It is possible to determine the confidence range described using simulation, with the following steps:

[0053] Step 1: Start independent simulation runs based on the selected process model at time-point t0 of the last error message m ε **N**;

[0054] Step 2: End a simulation run as soon as the required final time-point t_e is reached;

[0055] Step 3: Repeat Step 2 until all simulation runs are finished;

[0056] Step 4: Sort the numbers $\hat{N}_i(t_e)$ of the errors generated in the i-th simulation run in the time period (t_0, t_e), i=1, ..., m, in descending order, and label the values sorted thus $\hat{N}_{(1)}(t_e), \ldots, \hat{N}_{(m)}(t_e)$; and

[0057] Step 5: Substitute

$$\hat{g}_U := \hat{N}_{(\lfloor m\cdot\alpha/2\rfloor)}(t_e) \quad \text{and}$$
$$\hat{g}_O := \hat{N}_{(\lceil m\cdot(1-\alpha/2)\rceil)}(t_e),$$

[0058]

[0059] i.e., eliminate the (100 · (1-α)/2)% lowest and highest values.

[0060] This produces the confidence range directly.

[0061] Each individual simulation run is based on a simulation algorithm, which is known from (cf. Brately, et al., 1987):

[0062] The simulated generation of intermediate arrival times for a non-homogeneous Poisson process is as follows:

Step 1: Substitute $\bar{\lambda} := \sup_{t \geq t_s}\{\lambda(t)\}$, where:

$$\lambda(t) := \left.\frac{di}{dt}\right|_t \tag{10}$$

Step 2: Generate a (pseudo) random variable X that is exponentially distributed with the parameter $\bar{\lambda}$, i.e., $X := -\log(U)/\bar{\lambda}$, where U is equally distributed over (0,1);

Step 3: Generate a random variable U that is equally distributed over (0,1); and

Step 4: If $U \leq \lambda(t_s + x) / \bar{\lambda}$, then substitute $t^* := t_s + X$; otherwise substitute $t_s := t_s + X$ and go to Step 1.

[0063] The example graph in Fig. 1 shows an accumulated number of errors during a given test period. From time-point t_0, it shows a prediction range KI for all time-points $t_0 + x$.

[0064] The intensity i is normally derived from equation (10) for λ. For example the result is as follows:

[0065] a) $\lambda(t) = a \cdot b \cdot c \cdot \exp\left(-bt^c\right) \cdot t^{c-1}$

[0066] ($\lambda(t)$ is strictly monotonously descending for $c \leq 1$, and unimodal for $c > 1$ with a definitive maximum at a point

[0067] $t_{max} = \sqrt[c]{\frac{c-1}{bc}}$).

[0068] b) Otherwise, $\bar{\lambda}$ is derived in accordance with the above comments as follows:

[0069]

$$\bar{\lambda} = \begin{cases} \lambda(t_s), & (c \leq 1) \vee (t_s \geq t_{max}) \\ \lambda(t_{max}) & \end{cases}$$

[0070] The graph in Fig. 2 shows the superimposed confidence ranges. In particular, this illustrates that possible forecasts become more scattered the further they extend into the future. In particular, confidence ranges calculated using different process models can be demonstrated in the same way as shown in Fig. 2.

[0071] Fig. 3 shows a flowchart for the steps of a method for predicting measurement data using given measurement data. In Step 301, a stochastic process, in particular a non-homogenous Poisson process (to represent a stochastic count process), is matched to given measurement data. In Step 302, simulation runs are run from time-point t_0 to a final time-point t_e that is to be forecast. In Step 303,

for each simulation run, forecast measurement data is determined and a prediction of measurement data is restricted to a range which is covered by the measurement data determined by the simulation runs (see Step 304). In Step 305, a confidence range is determined in which a given proportion of the lowest and highest forecast measurement data is ignored in each case (this corresponds to the aforementioned range). The method terminates in Step 306.

[0072] Fig. 4 shows a further flowchart for the steps of a method for predicting measurement data using given measurement data. In Step 401, a stochastic process, in particular a non-homogenous Poisson process, is matched to the given measurement data. Probability values are determined using the stochastic process, and these are sorted according to size around an expected value (see Step 402). This sort operation results in the definition of a range, namely a confidence range in this case. The breadth of the confidence range is determined by comparing the accumulated probabilities with a given threshold. As described above, the confidence range gives a distribution or uncertainty, respectively, of a time-point t_0 in the future, which allows the measurement data to be estimated in the future (see Step 403). The method terminates in Step 404.

[0073] Fig. 5 shows a processor unit PRZE that may be used to implement the inventive method. The processor unit PRZE comprises a processor CPU, a memory unit MEM, and an input/output interface IOS, which is used in different ways via an interface IFC: a graphics interface allows output to be viewed on a monitor MON and/or output to a printer PRT. Inputs are entered via a mouse MAS or a keyboard TAST. The processor unit PRZE also includes a data bus BUS, which provides the connection between a memory unit MEM, the processor CPU and the input/output interface IOS. It is also possible to connect additional components to the data bus BUS, e.g. additional memory, data storage (hard disk) or scanner.

[0074] The C programming language is used in the following examples, which show an algorithm to define confidence ranges for forecasts and an algorithm for simulated definition of confidence ranges for forecasts.

[0075] Program 1:

[0076] /* Definition of confidence ranges for forecasts */

[0077] /* based on the generalized Goel-Okomoto model */

```
#include <stdlib.h>
#include <math.h>
#include <stdio.h>

#define true   1
#define false -1

double mv_genGO(double,double,double,double); double poisson(double,long); void ki_nhpp();
int main(argc,argv)
int argc;
char *argv[];
{
double a,b,c,bt,st,kn;
long low,upp,lauf;

if (argc<7) {
printf("\n\nZuwenig Argumente! \n\n");
printf("Aufruf: %s <Par1> <Par2> <Par3> <Startzeit> <Endzeit>",
"<KNiveau>\n\n", argv[0]); return 1;
 }

a = atof(argv[1]);
b = atof(argv[2]);
c = atof(argv[3]);
bt= atof(argv[4]);
st= atof(argv[5]);
kn= atof(argv[6]);

for (lauf=1;lauf< ;lauf++) {
ki_nhpp(mv_genGO,a,b,c,bt,bt+lauf*(st-bt)/10.,kn,&low,&upp);
printf("Zeitpunkt: %8.2f     Fehlerintervall: [%d,%d]\n",
bt+lauf*(st-bt)/10., low, upp);
 }
return 0;
}

double mv_genGO(x,a,b,c)
double x,a,b,c;
{ return( a*(1.0-exp(-b*pow(x,c))) ); }

double poisson(lambda,wert)
double lambda;
long wert;
{
long i;
double itval,hv;

if (lambda<600) {
itval = exp(-lambda);
for (i=wert;i>=1;i--) { itval *= lambda/(double)i; }
 }
```

[0078]

[0079]

```
else {
hv = exp(-lambda/(double)wert);
itval = 1.0;
for (i=wert;i>=1;i--) { itval *= lambda/(double)i*hv; }
 }
return ( itval );
}

void ki_nhpp(mv_nhpp, par1_nhpp, par2_nhpp, par3_nhpp,
start_time, stop_time, k_niveau, lower, upper) double mv_nhpp(double,double,double,double);
    double par1_nhpp, par2_nhpp, par3_nhpp, start_time, stop_time, k_niveau; long *lower, *upper;
{
long lauf;
int lborder,mod_low,mod_upp;
double sum,tmp_mv, val_l, val_u;

tmp_mv = mv_nhpp(stop_time,par1_nhpp,par2_nhpp,par3_nhpp) -
mv_nhpp(start_time,par1_nhpp,par2_nhpp,par3_nhpp); lauf = (long)tmp_mv;
*lower = lauf-1;
*upper = lauf+1; mod_low= false; mod_upp= false; sum    = poisson(tmp_mv,lauf); val_l  =
    poisson(tmp_mv,*lower); val_u  = poisson(tmp_mv,*upper);
while (sum<k_niveau) {
if (val_l<val_u) {
sum += val_u;
(*upper)++;
lborder = false;
mod_upp = true;
val_u  = poisson(tmp_mv,*upper);
  }
else {
sum += val_l;
(*lower)--;
lborder = true;
mod_low = true;
val_l  = poisson(tmp_mv,*lower);
  }
 }

if (lborder == true) { (*lower)++; }
else              { (*upper)--; }

if (mod_low == false) { (*lower)++; }
if (mod_upp == false) { (*upper)--; }

return;
}
```

Program 2:

[0080] /* Simulated definition of confidence ranges for forecasts */

[0081] /* based on the generalized Goel-Okomoto model */

```
#include <stdlib.h>
#include <math.h>
#include <time.h>
#include <stdio.h>
#include <values.h>

#define true   1
#define false -1

double drand48(void);
void srand48(long);

double sim_exp(double); double lambda_genGO(double,double,double,double); void sim_nhpp();
int main(argc,argv)
int argc;
char *argv[];
{
time_t t; double a,b,c,bt,st,pnt[1000000],check_time[12]; long lauf,no_pnt,seed_run; int clauf;
FILE *datei;
if (argc<6) {
printf("\n\nZuwenig Argumente! \n\n");
printf("Aufruf: %s <Par1> <Par2> <Par3> <Startzeit> <Endzeit>\n\n",
argv[0]); return 1;
 }

datei = fopen("sim.seed","r");
if (datei==NULL) {
seed_run = 1;
 }
else {
fscanf(datei,"%6d",&seed_run); fclose(datei); seed_run++;
 }

datei = fopen("sim.seed","w+");
fprintf(datei, "%6d\n", seed_run );
fclose(datei);

 time (&t) ;                  /* Initialisierung des      */
 t += seed_run*100 ;          /* Zufallszahlengenerators  */
srand48 ((unsigned long) t) ;  /* mit Hilfe der Systemzeit */
a = atof(argv[1]);
b = atof(argv[2]);
c = atof(argv[3]);
bt= atof(argv[4]);
st= atof(argv[5]);

sim_nhpp(lambda_genGO,a,b,c,bt,st,&pnt,&no_pnt);
for (lauf=1;lauf<=no_pnt;lauf++) {
printf("%15.7f %10d \n", pnt[lauf], lauf);
 }
```

[0082]

[0083]

```
datei = fopen("ki.tmp","a");
for (lauf=1;lauf< ;lauf++) {
check_time[lauf] = bt+lauf*(st-bt)/10.;
 }
check_time[11] = pnt[no_pnt]+1; /* größer als die größte
simulierte Zeit */
clauf = 1;
for (lauf=1;lauf<=no_pnt;lauf++) {
while (pnt[lauf]>=check_time[clauf]) { fprintf(datei, "%8.2f %6d ", check_time[clauf], lauf-1); clauf++;
  }
 }

if (pnt[no_pnt] <check_time[10]) {
for (lauf=clauf;lauf< ;lauf++) {  fprintf(datei, "%8.2f %6d ", check_time[lauf], no_pnt);
  }
 }

fprintf(datei, "\n");
fclose(datei);

return 0;
}

double sim_exp(lambda)
double lambda;
{ return( -log(drand48())/lambda ); }

double lambda_genGO(x,a,b,c)
double x,a,b,c;
{ return( a*b*c*pow(x,c-1)*exp(-b*pow(x,c)) ); }

void sim_nhpp(lambda_nhpp, par1_nhpp, par2_nhpp, par3_nhpp,
start_time, stop_time, path, no_points) double lambda_nhpp(double,double,double,double); double
    par1_nhpp, par2_nhpp, par3_nhpp, start_time, stop_time; double path[]; long *no_points;
{
double sim_time,x,u,x_bar,lambda_bar;
*no_points=0;
sim_time = start_time;

do {
if (par3_nhpp<=1) { lambda_bar = lambda_nhpp(sim_time,par1_nhpp,par2_nhpp,par3_nhpp);
  }
else {
x_bar = pow((par3_nhpp-1.0)/par2_nhpp/par3_nhpp,1.0/par3_nhpp);
if (sim_time>=x_bar) {
lambda_bar = lambda_nhpp(sim_time,par1_nhpp,par2_nhpp,par3_nhpp);
   }
else {
lambda_bar = lambda_nhpp(x_bar,par1_nhpp,par2_nhpp,par3_nhpp);
   }
  }

x = sim_exp(lambda_bar);
u = drand48();

 if (u<=lambda_nhpp(sim_time+x,par1_nhpp,par2_nhpp,par3_nhpp)/lambda_bar) { (*no_points)++;
     path[*no_points]=sim_time+x;
   }
 sim_time+=x;
  }
 while (sim_time<=stop_time);
 return;
 }
```

[0084] Program 3:

[0085] /* Definition of confidence ranges from the simulation data */

[0086] /* (the simulation data is sorted into ascending order) */

```
#include <stdlib.h>
#include <math.h>
#include <stdio.h>

int qsort_icmp(int*,int*);
int qsort_icmp(x,y)
int *x, *y;
{
if (*x<*y)      { return ( -1 ); }
else if (*x==*y) { return (  0 ); }
else            { return (  1 ); }
}

int main(argc,argv)
int argc;
char *argv[];
{
int pnt[11][100000];
int qs[100000];
char *dname;
int frac,i;
long lauf,lower_bound,upper_bound;
long l,no_pnt,seed_run;
double ctime[11],x;
FILE *datei;


if (argc<3) {
printf("\n\nZuwenig Argumente! \n\n"); printf("Aufruf: %s <Dateiname> <Konfidenzniveau (in
   %%)>\n\n", argv[0]); return 1;
 }

dname = argv[1];
frac  = 100-atoi(argv[2]);
lauf = 0;

datei = fopen(dname,"r");
if (datei==NULL) { return 1; }
else {
while (!feof(datei)) {
lauf++;
for (i=1;i<=9;i++) {
fscanf(datei,"%8lf %6d ", &ctime[i],  &pnt[i][lauf]);
    }
fscanf(datei,"%8lf %6d \n", &ctime[10],  &pnt[10][lauf]);
   }
fclose(datei);
 }

lower_bound = (long)floor(lauf*frac/200.); upper_bound = (long)ceil(lauf*(200.-frac)/200.);
if (lower_bound<1) {lower_bound = 1;}
```

[0087]

```
printf("\n\n%2d%%-Sicherheitsbereich bei %d Simulationsläufen\n\n",
100-frac,lauf);
for (i=1;i< ;i++) {
for (l=1;l<=lauf;l++) {
qs[l] = pnt[i][l];
   }

qsort(&qs[1], lauf, sizeof(int), &qsort_icmp);
printf("Zeitpunkt: %8.2f    Fehlerintervall: [%d,%d]\n",
ctime[i], qs[lower_bound], qs[upper_bound]);
 }

return 0 ;
}
```

[0088] The above-described method and apparatus are illustrative of the principles of the present invention. Numerous modifications and adaptations will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.

ABSTRACT

[0089] A method and an arrangement are provided for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. Simulation runs are carried out from a given time-point until a final time-point. The forecast measurement data is determined for each simulation run. Measurement data for the final time-point is predicted within a range of values, which is determined by the forecast measurement data.

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[~~Description~~]**SPECIFICATION**

[~~Method and arrangement for predicting measurement data using given measurement data~~]

TITLE

METHOD AND ARRANGEMENT FOR PREDICTING MEASUREMENT DATA USING GIVEN MEASUREMENT DATA

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates to a method and arrangement for predicting measurement data using given measurement data.

Description of the Related Art

[0002] A technical system often requires facilities for forecasting based on known (measurement) data, particularly in the context of error susceptibility or cost estimates.

[0003] Forecasts generated by experts are generally subject to errors. Experts cannot carry out exact analyses, at least of highly complex systems.

[0004] A stochastic point process, in particular a Poisson process, is described in [~~[1]~~]**Sidney I. Resnick: "Adventures** ~~in~~ **in Stochastic Processes", Birkhäuser Boston, 1992, ISBN 3-7643-3591-2, pp. 303-317 (Resnick)**.

Summary of the Invention

[0005] The object of the invention is to allow the automatic prediction (forecast) of measurement data using given measurement data.

[0006] This object is achieved in accordance with the [~~features of the independent patent claims. Developments~~]**method and apparatus described below; developments** of the invention are **also** described in the [~~dependent~~]**following** [~~claims~~]**text**.

[0007] In order to achieve [~~the~~]**this** object, a method is [~~proposed~~]**provided** for predicting measurement data using given measurement data, in which a

stochastic process is matched to the given measurement data. Simulation runs are carried out from a given time-point until a final time-point. The forecast measurement data is determined for each simulation run. Measurement data for the final time-point is predicted within a range of values, which is governed by the forecast measurement data.

[0008] One development is to define a confidence range for the prediction of measurement data, where the a% lowest and b% highest forecast measurement data are eliminated. In particular, a% can equal b%. For example, a 95% confidence range can thus be defined by ignoring the 2.5% lowest and 2.5% highest forecast measurement data.

[0009] **One advantage is that the measurement data can be predicted (forecast) with an accuracy that is within a confidence range, from a given time-point. This makes it possible to identify~~ e.g.,~~, e.g., the feasibility or impossibility of a task associated with the measurement data, at an early stage. Appropriate measures can therefore be initiated in order to counteract forecast impossibility.**

[0010] [~~One advantage is that the measurement data can be predicted (forecast) with an accuracy that is within a confidence range, from a given time-point. This makes it possible to identify~~][~~ e.g.~~][~~ the feasibility or impossibility of a task associated with the measurement data, at an early stage. Appropriate measures can therefore be initiated in order to counteract forecast impossibility.~~]This is particularly important in the case of a complex system, e.g., a software development process, where the extent to which a schedule can be followed before the software is completed can be shown in a subsequent test phase. Even more important in this context is the ability to adopt countermeasures at an early stage if a delay has been clearly identified, e.g., in an integration test phase. This firstly affects the feasibility of the specified deadline (timescale) and secondly directly affects costs, since non-compliance with the agreed timescale often results in additional costs.

[0011] One refinement is for the stochastic process to be a non-homogeneous Poisson process.

[0012] In particular, the measurement data may in one refinement comprise numbers of errors. This applies to software development, for example, where the

level of maturity is documented in accordance with the errors measured in a test phase. Completion is directly dependent on this level of maturity. In other words, the software cannot be delivered to customers until most of the errors have been removed from the software. This is particularly important with regard to resources (required to test and correct errors) and costs (due to delayed delivery).

[0013] In order to achieve the object **of the invention**, a method is also [~~proposed~~]**provided** for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. A range is ascertained, by sorting the probability values generated by the stochastic process according to size, around an expected value. Measurement data is predicted on the basis of this range, and in particular the probability values within the range.

[0014] One development is for the probability values generated by the stochastic process to be sorted symmetrically by size around the expected value. In particular, this means that the highest probability value represents the middle of the range, i.e., the expected value, whereas the next highest probability value is arranged to the right or left of the expected value. The next highest probability value is then arranged symmetrically on the other side of the expected value, in turn.

[0015] This analytical (design) procedure provides a range, where the breadth of the range in turn indicates which probability values are significant in the prediction of the measurement data.

[0016] In one particular refinement, the breadth of the range is determined by ignoring the probability values that lie below a given threshold.

[0017] This produces a range (confidence range), which has a specific breadth as a result of the threshold. This breadth corresponds to the certainty with which the measurement data is predicted.

[0018] If one assumes that the stochastic process is a non-homogeneous Poisson process, then the non-homogeneous Poisson process defines a step size, particularly on a time axis t, which indicates when the next error will occur. One characteristic of the non-homogeneous Poisson process is that it has no memory, so that a "no-memory" search is carried out from each error that occurs at a specific time-point, for a time-point that indicates the next error.

[0019] In order to achieve the object **of the invention**, an arrangement is also [~~proposed~~]**provided** for predicting measurement data using given measurement data[~~, whereby~~] **that has** a processor unit [~~is provided~~]and **is** configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) simulation runs can be carried out from a given time-point until a final time-point;

c) the forecast measurement data can be determined for each simulation run; **and**

d) the prediction of measurement data for the final time-point can be predicted within a range of values, which is determined by the forecast measurement data.

[0020] In order to achieve the object **of the invention**, an arrangement is further [~~proposed~~]**provided** for predicting measurement data using given measurement data[~~, whereby~~] **that has** a processor unit [~~is provided~~]and **is** configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) a range can be ascertained by sorting probability values generated by the stochastic process according to size around an expected value; **and**

c) the measurement data is predicted within the limits of the range.

[0021] The arrangements are particularly suitable for carrying out the inventive method or the developments described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Exemplary embodiments of the invention are shown and explained below with reference to the drawings, in which:

Fig. 1 is a graph showing an accumulated number of errors over a test period;

Fig. 2 is a graph showing the superimposed confidence ranges for different process models;

Fig. 3 is a flowchart showing the steps in a method for predicting measurement data using given measurement data;

Fig. 4 is a further flowchart showing the steps in a method for predicting measurement data using given measurement data; **and**

Fig. 5 [~~shows~~]**is a block diagram showing** a processor unit.

DETAILED DESCRIPTION OF THE INVENTION

[0023] In order to be able to forecast a number of [~~errors to be~~]expected **errors** in a technical process, e.g.**,** in a software development process, non-homogeneous Poisson processes (NHPP) are calibrated[~~,~~] **(**i.e.**,** matched to measurement data, [~~e.g.~~]**such as** the occurrence of errors over time[~~,~~]**)** as follows:

[0024] The following equation describes a counting process associated with the stochastic point process (non-homogeneous Poisson process):

[0025]

$$\{N(t)\}_{t \in \mathbf{R}^+} \qquad (1)$$

[0026] and a time-point t_0 defines the end of a test period, i.e.**,** a time-point at which the given data ends. The stochastic processes

$$\{U(t)\}_{t \in \mathbf{R}^+} \quad \text{and} \qquad (2)$$

[0027]

$$\{O(t)\}_{t \in \mathbf{R}^+} \qquad (3)$$

[0028] are searched with

[0029]

$$P\left(U(t) \le N(t) - N(t_0) \le O(t) \,\middle|\, N(t_0) = n_0\right) \ge \alpha \qquad (4),$$

[0030] for all time-points where t>t0 and given values $\alpha \in (0.1)$ (confidence level) and $n0 \in N$. In particular, the following text examines the increases in the stochastic countings process in relation to the time-point t_0.

[0031] In the present case, where equation (1) represents a non-homogeneous Poisson process, the following equation (cf. [~~[1]~~]**Resnick**)

$$P\left(N(t_1) - N(t_0) = \ell\right) = \exp\left(-\left[i(t_1) - i(t_0)\right]\right) \cdot \frac{\left[i(t_1) - i(t_0)\right]^{\ell}}{\ell!} \quad (5)$$

[0032]

[0033] applies for

$$0 \le t_0 < t_1 < \infty, \quad \ell \in \mathbf{N}_0 \quad (6)$$

[0034]

[0035] and an intensity (mean measure, mean value function) of

[0036]

$$i: \mathbf{R}^+ \rightarrow \mathbf{R}^+, t \mapsto i(t) = EN(t) \quad (7).$$

[0037] Since the nature of the Poisson process dictates that the increases (error increases in this case) are independent of previous increases, equation (5) for the time-points $t>t_0$ to define a (minimum) range

$$[g_u, g_o] \equiv [g_u(t), g_o(t)] \subset \mathbf{N}_0 \quad (8)$$

[0038]

[0039] can be simplified to

$$\sum_{\ell=g_u}^{g_o} P\left(N(t) - N(t_0) = \ell\right) \ge \alpha \quad (9).$$

[0040]

[0041] Due to the unimodal nature of the Poisson count density, a range $[g_u, g_o]$ can be determined as follows:

[0042] Step 1: Sort the elementary probabilities

$$p_\ell := P\left(N(t) - N(t_0) = \ell\right), \quad \ell \in \mathbf{N}_0$$

[0043]

[0044] into descending order and label the values sorted thus using

$$p_{(0)}, p_{(1)}, \ldots \quad (\text{i.e. } \{p_0, p_1, \ldots\} = \{p_{(0)}, p_{(1)}, \ldots\} \text{ and } p_{(0)} \ge p_{(1)} \ge \ldots);$$

[0045]

[0046] Step 2: Determine

$$\ell_{min} := \min\left\{\ell \in \mathbf{N}_0 \,\middle|\, \sum_{i=0}^{\ell} P(i) \geq \alpha\right\};$$

;

[0047] Step 3: Determine an index set

$$I := \left\{i_0, \ldots, i_{\ell_{min}}\right\} \subset \mathbf{N}_0 \quad \textbf{where}$$

[0048]

$$\left\{p_{i_0}, \ldots, p_{i_{\ell_{min}}}\right\} = \left\{P(0), \ldots, P\left(\ell_{min}\right)\right\};$$

[0049]

[0050] Step 4: Substitute $g_u := \min_{i \in I}\{i\}$ and [-] $g_o := \max_{i \in I}\{i\}$.

[0051] The range from equation (8) is also referred to as the forecast range.

Stochastic simulation (second approach)

[0052] It is possible to determine the confidence range described using simulation, with the following steps:

[0053] Step 1: Start independent simulation runs based on the selected process model at time-point t0 of the last error message m ε **N**;

[0054] Step 2: End a simulation run as soon as the required final time-point t_e is reached;

[0055] Step 3: Repeat Step 2 until all simulation runs are finished;

[0056] Step 4: Sort the numbers $\hat{N}_i(t_e)$ of the errors generated in the i-th simulation run in the time period (t_0, t_e), i=1, ..., m, in descending order, and label the values sorted thus [;] $\hat{N}_{(1)}(t_e), \ldots, \hat{N}_{(m)}(t_e)$; and

[0057] Step 5: Substitute

$$\hat{g}_u := \hat{N}_{(\lfloor m \cdot \alpha / 2 \rfloor)}(t_e) \quad \text{and}$$
$$\hat{g}_o := \hat{N}_{(\lceil m \cdot (1-\alpha/2) \rceil)}(t_e),$$

[0058]

[0059] i.e., eliminate the (100[?] · (1-α)/2)% lowest and highest values.

[0060] This produces the confidence range directly.

[0061] Each individual simulation run is based on a simulation algorithm, which is known from (cf. [[~~2~~]]**Bratelv, et al., 1987**):

[0062] [~~Simulated~~]**The simulated** generation of intermediate arrival times for a non-homogeneous Poisson process **is as follows**:

Step 1: Substitute $\bar{\lambda} := \sup_{t \ge t_s} \{\lambda(t)\}$, where:

$$\lambda(t) := \left.\frac{di}{dt}\right|_t \qquad (10).$$

Step 2: Generate a (pseudo) random variable X that is exponentially distributed with the parameter $\bar{\lambda}$, i.e.**,** $X := -\log(U) / \bar{\lambda}$, where U is equally distributed over (0,1)[~~.~~]**;**

Step 3: Generate a random variable U that is equally distributed over (0,1)[~~.~~]**; and**

Step 4: If $U \le \lambda(t_s + X) / \bar{\lambda}$, then substitute $t^* := t_s + X$; otherwise substitute $t_s := t_s + X$ and go to Step 1.

[0063] The example graph in Fig. 1 shows an accumulated number of errors during a given test period. From time-point t_0, it shows a prediction range **KI** for all time-points $t_0 + x$.

[0064] The intensity i is normally derived from equation (10) for λ. For example the result is as follows:

[0065] a) $\lambda(t) = a \cdot b \cdot c \cdot \exp\left(-bt^c\right) \cdot t^{c-1}$

[0066] ($\lambda(t)$ is strictly monotonously descending for [~~, and unimodal for~~] [~~with a definitive maximum at a point~~] $c \le 1$**, and unimodal for** $c > 1$ **with a definitive maximum at a point**

[0067] $t_{max} = \sqrt[c]{\frac{c-1}{bc}}$).

[0068] b) Otherwise, $\bar{\lambda}$ is derived in accordance with the above comments as follows:

[0069]

$$\bar{\lambda} = \begin{cases} \lambda(t_S), & (c \le 1) \vee (t_S \ge t_{max}) \\ \lambda(t_{max}) & \end{cases}$$

[0070] The graph in Fig. 2 shows the superimposed confidence ranges. In particular, this illustrates that possible forecasts become more scattered the further they extend into the future. In particular, confidence ranges calculated using different process models can be demonstrated in the same way as shown in Fig. 2.

[0071] Fig. 3 shows a flowchart for the steps of a method for predicting measurement data using given measurement data. In Step 301, a stochastic process, in particular a non-homogenous Poisson process (to represent a stochastic count process), is matched to given measurement data. In Step 302, simulation runs are run from time-point t_0 to a final time-point t_e that is to be forecast. In Step 303, for each simulation run, forecast measurement data is determined and a prediction of measurement data is restricted to a range which is covered by the measurement data determined by the simulation runs (see Step 304). In Step 305, a confidence range is determined in which a given proportion of the lowest and highest forecast measurement data is ignored in each case (this corresponds to the aforementioned range). The method terminates in Step 306.

[0072] Fig. 4 shows a further flowchart for the steps of a method for predicting measurement data using given measurement data. In Step 401, a stochastic process, in particular a non-homogenous Poisson process, is matched to the given measurement data. Probability values are determined using the stochastic process, and these are sorted according to size around an expected value (see Step 402). This sort operation results in the definition of a range, namely a confidence range in this case. The breadth of the confidence range is determined by comparing the accumulated probabilities with a given threshold. As described above, the confidence range gives a distribution or uncertainty, respectively, of a time-point t_0 in the future, which allows the measurement data to be estimated in the future (see Step 403). The method terminates in Step 404.

[0073] Fig. 5 shows a processor unit PRZE **that may be used to implement the inventive method**. The processor unit PRZE comprises a processor CPU, a memory unit MEM, and an input/output interface IOS, which is used in different ways via an interface IFC: a graphics interface allows output to be viewed on a monitor MON and/or output to a printer PRT. Inputs are entered via a mouse MAS or a keyboard TAST. The processor unit PRZE also includes a data bus BUS, which provides the connection between a memory unit MEM, the processor CPU and the input/output interface IOS. It is also possible to connect additional components to the data bus BUS, e.g. additional memory, data storage (hard disk) or scanner.

[0074] The C programming language is used in the following examples, which show an algorithm to define confidence ranges for forecasts and an algorithm for simulated definition of confidence ranges for forecasts.

[0075] Program 1:

[0076] /* Definition of confidence ranges for forecasts */

[0077] /* based on the generalized Goel-Okomoto model */

```c
#include <stdlib.h>
#include <math.h>
#include <stdio.h>

#define true   1
#define false -1

double mv_genGO(double,double,double,double); double poisson(double,long); void ki_nhpp();
int main(argc,argv)
int argc;
char *argv[];
{
double a,b,c,bt,st,kn;
long low,upp,lauf;

if (argc<7) {
printf("\n\nZuwenig Argumente! \n\n");
printf("Aufruf: %s <Par1> <Par2> <Par3> <Startzeit> <Endzeit>",
"<KNiveau>\n\n", argv[0]); return 1;
 }

a = atof(argv[1]);
b = atof(argv[2]);
c = atof(argv[3]);
bt= atof(argv[4]);
st= atof(argv[5]);
kn= atof(argv[6]);

for (lauf=1;lauf< ;lauf++) {
ki_nhpp(mv_genGO,a,b,c,bt,bt+lauf*(st-bt)/10.,kn,&low,&upp);
printf("Zeitpunkt: %8.2f    Fehlerintervall: [%d,%d]\n",
bt+lauf*(st-bt)/10., low, upp);
 }
return 0;
}

double mv_genGO(x,a,b,c)
double x,a,b,c;
{ return( a*(1.0-exp(-b*pow(x,c))) ); }

double poisson(lambda,wert)
double lambda;
long wert;
{
long i;
double itval,hv;

if (lambda<600) {
itval = exp(-lambda);
for (i=wert;i>=1;i--) { itval *= lambda/(double)i; }
 }
```

[0078]

[0079]

```
else {
hv = exp(-lambda/(double)wert);
itval = 1.0;
for (i=wert;i>=1;i–) { itval *= lambda/(double)i*hv; }
 }
return ( itval );
}

void ki_nhpp(mv_nhpp, par1_nhpp, par2_nhpp, par3_nhpp,
start_time, stop_time, k_niveau, lower, upper) double mv_nhpp(double,double,double,double);
   double par1_nhpp, par2_nhpp, par3_nhpp, start_time, stop_time, k_niveau; long *lower, *upper;
{
long lauf;
int lborder,mod_low,mod_upp;
double sum,tmp_mv, val_l, val_u;

tmp_mv = mv_nhpp(stop_time,par1_nhpp,par2_nhpp,par3_nhpp) -
mv_nhpp(start_time,par1_nhpp,par2_nhpp,par3_nhpp); lauf = (long)tmp_mv;
*lower = lauf-1;
*upper = lauf+1; mod_low= false; mod_upp= false; sum    = poisson(tmp_mv,lauf); val_l  =
   poisson(tmp_mv,*lower); val_u  = poisson(tmp_mv,*upper);
while (sum<k_niveau) {
if (val_l<val_u) {
sum += val_u;
(*upper)++;
lborder = false;
mod_upp = true;
val_u  = poisson(tmp_mv,*upper);
  }
else {
sum += val_l;
(*lower)–;
lborder = true;
mod_low = true;
val_l  = poisson(tmp_mv,*lower);
  }
 }

if (lborder == true) { (*lower)++; }
else             { (*upper)–; }

if (mod_low == false) { (*lower)++; }
if (mod_upp == false) { (*upper)–; }

return;
}
```

Program 2:

[0080] /* Simulated definition of confidence ranges for forecasts */

[0081] /* based on the generalized Goel-Okomoto model */

```
#include <stdlib.h>
#include <math.h>
#include <time.h>
#include <stdio.h>
#include <values.h>

#define true   1
#define false -1

double drand48(void);
void srand48(long);

double sim_exp(double); double lambda_genGO(double,double,double,double); void sim_nhpp();
int main(argc,argv)
int argc;
char *argv[];
{
time_t t; double a,b,c,bt,st,pnt[1000000],check_time[12]; long lauf,no_pnt,seed_run; int clauf;
FILE *datei;
if (argc<6) {
printf("\n\nZuwenig Argumente! \n\n");
printf("Aufruf: %s <Par1> <Par2> <Par3> <Startzeit> <Endzeit>\n\n",
argv[0]); return 1;
 }

datei = fopen("sim.seed","r");
if (datei==NULL) {
seed_run = 1;
 }
else {
fscanf(datei,"%6d",&seed_run); fclose(datei); seed_run++;
 }

datei = fopen("sim.seed","w+");
fprintf(datei, "%6d\n", seed_run );
fclose(datei);

 time (&t) ;                  /* Initialisierung des      */
 t += seed_run*100 ;          /* Zufallszahlengenerators  */
srand48 ((unsigned long) t) ; /* mit Hilfe der Systemzeit */
a = atof(argv[1]);
b = atof(argv[2]);
c = atof(argv[3]);
bt= atof(argv[4]);
st= atof(argv[5]);

sim_nhpp(lambda_genGO,a,b,c,bt,st,&pnt,&no_pnt);
for (lauf=1;lauf<=no_pnt;lauf++) {
printf("%15.7f %10d \n", pnt[lauf], lauf);
 }
```

[0082]

[0083]

```
datei = fopen("ki.tmp","a");
for (lauf=1;lauf< ;lauf++) {
check_time[lauf] = bt+lauf*(st-bt)/10.;
 }
check_time[11] = pnt[no_pnt]+1; /* größer als die größte
simulierte Zeit */
clauf = 1;
for (lauf=1;lauf<=no_pnt;lauf++) {
while (pnt[lauf]>=check_time[clauf]) { fprintf(datei, "%8.2f %6d ", check_time[clauf], lauf-1); clauf++;
  }
 }

if (pnt[no_pnt] <check_time[10]) {
for (lauf=clauf;lauf< ;lauf++) {  fprintf(datei, "%8.2f %6d ", check_time[lauf], no_pnt);
  }
 }

fprintf(datei, "\n");
fclose(datei);

return 0;
}

double sim_exp(lambda)
double lambda;
{ return( -log(drand48())/lambda ); }

double lambda_genGO(x,a,b,c)
double x,a,b,c;
{ return( a*b*c*pow(x,c-1)*exp(-b*pow(x,c)) ); }

void sim_nhpp(lambda_nhpp, par1_nhpp, par2_nhpp, par3_nhpp,
start_time, stop_time, path, no_points) double lambda_nhpp(double,double,double,double); double
    par1_nhpp, par2_nhpp, par3_nhpp, start_time, stop_time; double path[]; long *no_points;
{
double sim_time,x,u,x_bar,lambda_bar;
*no_points=0;
sim_time = start_time;

do {
if (par3_nhpp<=1) { lambda_bar = lambda_nhpp(sim_time,par1_nhpp,par2_nhpp,par3_nhpp);
  }
else {
x_bar = pow((par3_nhpp-1.0)/par2_nhpp/par3_nhpp,1.0/par3_nhpp);
if (sim_time>=x_bar) {
lambda_bar = lambda_nhpp(sim_time,par1_nhpp,par2_nhpp,par3_nhpp);
   }
else {
lambda_bar = lambda_nhpp(x_bar,par1_nhpp,par2_nhpp,par3_nhpp);
   }
  }

x = sim_exp(lambda_bar);
u = drand48();


if (u<=lambda_nhpp(sim_time+x,par1_nhpp,par2_nhpp,par3_nhpp)/lambda_bar) { (*no_points)++;
    path[*no_points]=sim_time+x;
  }
sim_time+=x;
 }
while (sim_time<=stop_time);
return;
}
```

[0084] Program 3:

[0085] /* Definition of confidence ranges from the simulation data */

[0086] /* (the simulation data is sorted into ascending order) */

```
#include <stdlib.h>
#include <math.h>
#include <stdio.h>

int qsort_icmp(int*,int*);
int qsort_icmp(x,y)
int *x, *y;
{
if (*x<*y)      { return ( -1 ); }
else if (*x==*y) { return (  0 ); }
else            { return (  1 ); }
}

int main(argc,argv)
int argc;
char *argv[];
{
int pnt[11][100000];
int qs[100000];
char *dname;
int frac,i;
long lauf,lower_bound,upper_bound;
long l,no_pnt,seed_run;
double ctime[11],x;
FILE *datei;


if (argc<3) {
printf("\n\nZuwenig Argumente! \n\n"); printf("Aufruf: %s <Dateiname> <Konfidenzniveau (in
    %%)>\n\n", argv[0]); return 1;
 }

dname = argv[1];
frac  = 100-atoi(argv[2]);
lauf = 0;

datei = fopen(dname,"r");
if (datei==NULL) { return 1; }
else {
while (!feof(datei)) {
lauf++;
for (i=1;i<=9;i++) {
fscanf(datei,"%8lf %6d ", &ctime[i],  &pnt[i][lauf]);
    }
fscanf(datei,"%8lf %6d \n", &ctime[10],  &pnt[10][lauf]);
  }
fclose(datei);
 }

lower_bound = (long)floor(lauf*frac/200.); upper_bound = (long)ceil(lauf*(200.-frac)/200.);
if (lower_bound<1) {lower_bound = 1;}
```

[0087]

```
printf("\n\n%2d%%-Sicherheitsbereich bei %d Simulationsläufen\n\n",
100-frac,lauf);
for (i=1;i< ;i++) {
for (l=1;l<=lauf;l++) {
qs[l] = pnt[i][l];
   }

qsort(&qs[1], lauf, sizeof(int), &qsort_icmp);
printf("Zeitpunkt: %8.2f     Fehlerintervall: [%d,%d]\n",
ctime[i], qs[lower_bound], qs[upper_bound]);
 }

return 0 ;
}
```

[0088] **The above-described method and apparatus are illustrative of the principles of the present invention.** [~~References:~~]

[[~~1]~~][~~Sidney I. Resnick: "Adventures~~][~~ in ~~][~~Stochastic Processes", Birkhäuser Boston, 1992, ISBN 3-7643-3591-2, pp. 303-317~~]

[[~~2]~~ ~~Brately et al., 1987~~]

Numerous modifications and adaptations will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.

[~~Abstract~~]

[~~Method and arrangement for predicting measurement data using given measurement data~~]**<u>ABSTRACT</u>**

<u>[0089]</u> A method and an arrangement are [~~proposed~~]**<u>provided</u>** for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. Simulation runs are carried out from a given time-point until a final time-point. The forecast measurement data is determined for each simulation run. Measurement data for the final time-point is predicted within a range of values, which is determined by the forecast measurement data.

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Description

Method and arrangement for predicting measurement data using given measurement data

The invention relates to a method and arrangement for predicting measurement data using given measurement data.

A technical system often requires facilities for forecasting based on known (measurement) data, particularly in the context of error susceptibility or cost estimates.

Forecasts generated by experts are generally subject to errors. Experts cannot carry out exact analyses, at least of highly complex systems.

A stochastic point process, in particular a Poisson process, is described in [1].

The **object** of the invention is to allow the automatic prediction (forecast) of measurement data using given measurement data.

This object is achieved in accordance with the features of the independent patent claims. Developments of the invention are described in the dependent claims.

In order to achieve the object, a method is proposed for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. Simulation runs are carried out from a given time-point until a final time-point. The forecast measurement data is determined for each simulation run. Measurement data for the final time-point

is predicted within a range of values, which is governed by the forecast measurement data.

One development is to define a confidence range for the prediction of measurement data, where the a% lowest and b% highest forecast measurement data are eliminated. In particular, a% can equal b%. For example, a 95% confidence range can thus be defined by ignoring the 2.5% lowest and 2.5% highest forecast measurement data.

One advantage is that the measurement data can be predicted (forecast) with an accuracy that is within a confidence range, from a given time-point. This makes it possible to identify e.g. the feasibility or impossibility of a task associated with the measurement data, at an early stage. Appropriate measures can therefore be initiated in order to counteract forecast impossibility. This is particularly important in the case of a complex system, e.g. a software development process, where the extent to which a schedule can be followed before the software is completed can be shown in a subsequent test phase. Even more important in this context is the ability to adopt countermeasures at an early stage if a delay has been clearly identified, e.g. in an integration test phase. This firstly affects the feasibility of the specified deadline (timescale) and secondly directly affects costs, since non-compliance with the agreed timescale often results in additional costs.

One refinement is for the stochastic process to be a non-homogeneous Poisson process.

In particular, the measurement data may in one refinement comprise numbers of errors. This applies to software development,

for example, where the level of maturity is documented in accordance with the errors measured in a test phase. Completion is directly dependent on this level of maturity. In other words, the software cannot be delivered to customers until most of the errors have been removed from the software. This is particularly important with regard to resources (required to test and correct errors) and costs (due to delayed delivery).

In order to achieve the object, a method is also proposed for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. A range is ascertained, by sorting the probability values generated by the stochastic process according to size, around an expected value. Measurement data is predicted on the basis of this range, and in particular the probability values within the range.

One development is for the probability values generated by the stochastic process to be sorted symmetrically by size around the expected value. In particular, this means that the highest probability value represents the middle of the range, i.e. the expected value, whereas the next highest probability value is arranged to the right or left of the expected value. The next highest probability value is then arranged symmetrically on the other side of the expected value, in turn.

This analytical (design) procedure provides a range, where the breadth of the range in turn indicates which probability values are significant in the prediction of the measurement data.

In one particular refinement, the breadth of the range is determined by ignoring the

probability values that lie below a given threshold.

This produces a range (confidence range), which has a specific breadth as a result of the threshold. This breadth corresponds to the certainty with which the measurement data is predicted.

If one assumes that the stochastic process is a non-homogeneous Poisson process, then the non-homogeneous Poisson process defines a step size, particularly on a time axis t, which indicates when the next error will occur. One characteristic of the non-homogeneous Poisson process is that it has no memory, so that a "no-memory" search is carried out from each error that occurs at a specific time-point, for a time-point that indicates the next error.

In order to achieve the object, an arrangement is also proposed for predicting measurement data using given measurement data, whereby a processor unit is provided and configured in such a way that:

a) a stochastic process can be matched to the given measurement data;
b) simulation runs can be carried out from a given time-point until a final time-point;
c) the forecast measurement data can be determined for each simulation run;
d) the prediction of measurement data for the final time-point can be predicted within a range of values, which is determined by the forecast measurement data.

In order to achieve the object, an arrangement is further proposed for predicting measurement data using given measurement data, whereby a processor unit is provided and configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) a range can be ascertained by sorting probability values generated by the stochastic process according to size around an expected value;

c) the measurement data is predicted within the limits of the range.

The arrangements are particularly suitable for carrying out the inventive method or the developments described above.

Exemplary embodiments of the invention are shown and explained below with reference to the drawings, in which:

Fig. 1 is a graph showing an accumulated number of errors over a test period;

Fig. 2 is a graph showing the superimposed confidence ranges for different process models;

Fig. 3 is a flowchart showing the steps in a method for predicting measurement data using given measurement data;

Fig. 4 is a further flowchart showing the steps in a method for predicting measurement data using given measurement data;

Fig. 5 shows a processor unit.

In order to be able to forecast a number of errors to be expected in a technical process, e.g. in a software development process, non-homogeneous Poisson

processes (NHPP) are calibrated, i.e. matched to measurement data, e.g. the occurrence of errors over time, as follows:

The following equation describes a counting process associated with the stochastic point process (non-homogeneous Poisson process):

$$\{N(t)\}_{t \in \mathbf{R}^+} \tag{1}$$

and a time-point t_0 defines the end of a test period, i.e. a time-point at which the given data ends. The stochastic processes

$$\{U(t)\}_{t \in \mathbf{R}^+} \quad \text{and} \tag{2}$$

$$\{O(t)\}_{t \in \mathbf{R}^+} \tag{3}$$

are searched with

$$P\Big(U(t) \le N(t) - N(t_0) \le O(t) \,\Big|\, N(t_0) = n_0\Big) \ge \alpha \tag{4}$$,

for all time-points where $t>t_0$ and given values $\alpha \in (0.1)$ (confidence level) and $n_0 \in \mathbf{N}$. In particular, the following text examines the increases in the stochastic countings process in relation to the time-point t_0.

In the present case, where equation (1) represents a non-homogeneous Poisson process, the following equation (cf. [1])

$$P\big(N(t_1) - N(t_0) = \ell\big) = \exp\big(-[i(t_1) - i(t_0)]\big) \cdot \frac{[i(t_1) - i(t_0)]^{\ell}}{\ell\,!} \tag{5}$$

applies for

$$0 \le t_0 < t_1 < \infty, \quad \ell \in \mathbf{N}_0 \tag{6}$$

and an intensity (mean measure, mean value function) of

$$i:\ \mathbf{R}^+ \to \mathbf{R}^+, t \mapsto i(t) = EN(t) \qquad (7).$$

Since the nature of the Poisson process dictates that the increases (error increases in this case) are independent of previous increases, equation (5) for the time-points $t > t_0$ to define a (minimum) range

$$[g_u, g_o] \equiv [g_u(t), g_o(t)] \subset \mathbf{N}_0 \qquad (8)$$

can be simplified to

$$\sum_{\ell = g_u}^{g_o} P\left(N(t) - N(t_0) = \ell\right) \geq \alpha \qquad (9).$$

Due to the unimodal nature of the Poisson count density, a range $[g_u, g_o]$ can be determined as follows:

Step 1: Sort the elementary probabilities

$$p_\ell := P\left(N(t) - N(t_0) = \ell\right),\ \ell \in \mathbf{N}_0$$

into descending order and label the values sorted thus using

$p_{(0)}, p_{(1)}, \ldots$ (i.e. $\{p_0, p_1, \ldots\} = \{p_{(0)}, p_{(1)}, \ldots\}$ and $p_{(0)} \geq p_{(1)} \geq \ldots$);

Step 2: Determine $\ell_{min} := \min\left\{\ell \in \mathbf{N}_0 \,\middle|\, \sum_{i=0}^{\ell} p_{(i)} \geq \alpha\right\}$; ;

Step 3: Determine an index set

$$I := \{i_0, \ldots, i_{\ell_{min}}\} \subset \mathbf{N}_0 \text{ where}$$

$$\left\{ Pi_0, \ldots, Pi_{\ell_{min}} \right\} = \left\{ P(0), \ldots, P(\ell_{min}) \right\};$$

Step 4: Substitute $g_u := \min_{i \in I}\{i\}$ and $g_o := \max_{i \in I}\{i\}$.

The range from equation (8) is also referred to as the forecast range.

Stochastic simulation (second approach)

It is possible to determine the confidence range described using simulation, with the following steps:

Step 1: Start independent simulation runs based on the selected process model at time-point t_0 of the last error message $m \in \mathbf{N}$;

Step 2: End a simulation run as soon as the required final time-point t_e is reached;

Step 3: Repeat Step 2 until all simulation runs are finished;

Step 4: Sort the numbers $\hat{N}_i(t_e)$ of the errors generated in the i-th simulation run in the time period (t_0, t_e), $i=1, \ldots, m$, in descending order, and label the values sorted thus $\hat{N}_{(1)}(t_e), \ldots, \hat{N}_{(m)}(t_e)$;

Step 5: Substitute

$$\hat{g}_u := \hat{N}_{(\lfloor m \cdot \alpha / 2 \rfloor)}(t_e) \quad \text{and}$$

$$\hat{g}_o := \hat{N}_{(\lceil m \cdot (1-\alpha/2) \rceil)}(t_e),$$

i.e. eliminate the (100?(1-α)/2)% lowest and highest values.

This produces the confidence range directly.

Each individual simulation run is based on a simulation algorithm, which is known from (cf. [2]):
Simulated generation of intermediate arrival times for a non-homogeneous Poisson process:

Step 1: Substitute $\bar{\lambda} := \sup_{t \geq t_s} \{\lambda(t)\}$, where:

$$\lambda(t) := \left. \frac{di}{dt} \right|_t \qquad (10).$$

Step 2: Generate a (pseudo) random variable X that is exponentially distributed with the parameter $\bar{\lambda}$, i.e. $X := -\log(U)/\bar{\lambda}$, where U is equally distributed over (0,1).

Step 3: Generate a random variable U that is equally distributed over (0,1).

Step 4: If $U \leq \lambda(t_s + X)/\bar{\lambda}$, then substitute $t^* := t_s + X$; otherwise substitute $t_s := t_s + X$ and go to Step 1.

The example graph in **Fig. 1** shows an accumulated number of errors during a given test period. From time-point t_0, it shows a prediction range for all time-points t_0 + x.

The intensity i is normally derived from equation (10) for λ. For example the result is as follows:

a) $\lambda(t) = a \cdot b \cdot c \cdot \exp\left(-bt^c\right) \cdot t^{c-1}$

($\lambda(t)$ is strictly monotonously descending for $c \leq 1$, and unimodal for $c > 1$ with a definitive maximum at a point $t_{max} = \sqrt[c]{\frac{c-1}{bc}}$).

b) Otherwise, $\bar{\lambda}$ is derived in accordance with the above comments as follows:

$$\bar{\lambda} = \begin{cases} \lambda(t_s), & (c \leq 1) \vee (t_s \geq t_{max}) \\ \lambda(t_{max}) \end{cases}$$

The graph in **Fig. 2** shows the superimposed confidence ranges. In particular, this illustrates that possible forecasts become more scattered the further they extend into the future. In particular, confidence ranges calculated using different process models can be demonstrated in the same way as shown in Fig. 2.

Fig. 3 shows a flowchart for the steps of a method for predicting measurement data using given measurement data. In Step 301, a stochastic process, in particular a non-homogenous Poisson process (to represent a stochastic count process), is matched to given measurement data. In Step 302, simulation runs are run from time-point t_0 to a final time-point t_e that is to be forecast. In Step 303, for each simulation run, forecast measurement data is determined and a prediction of measurement data is restricted to a range which is covered by the measurement data determined by the simulation runs (see Step 304). In Step 305, a confidence range is determined in which a given proportion of the lowest and highest forecast measurement data is ignored in each case (this corresponds to the aforementioned range). The method terminates in Step 306.

Fig. 4 shows a further flowchart for the steps of a method for predicting measurement data using given measurement data. In Step 401, a stochastic process, in particular a non-homogenous Poisson process, is matched to the given measurement data. Probability values are determined using the stochastic process, and these are sorted according to size around an expected value (see Step 402). This sort operation results in the definition of a range, namely a confidence range in this case. The breadth of the confidence range is determined by comparing the accumulated probabilities with a given threshold. As described above, the confidence range gives a distribution or uncertainty, respectively, of a time-point t_0 in the future, which allows the measurement data to be estimated in the future (see Step 403). The method terminates in Step 404.

Fig. 5 shows a processor unit PRZE. The processor unit PRZE comprises a processor CPU, a memory unit MEM, and an input/output interface IOS, which is used in different ways via an interface IFC: a graphics interface allows output to be viewed on a monitor MON and/or output to a printer PRT. Inputs are entered via a mouse MAS or a keyboard TAST. The processor unit PRZE also includes a data bus BUS, which provides the connection between a memory unit MEM, the processor CPU and the input/output interface IOS. It is also possible to connect additional components to the data bus BUS, e.g. additional memory, data storage (hard disk) or scanner.

The C programming language is used in the following examples, which show an algorithm to define confidence ranges for forecasts and an algorithm for simulated definition of confidence ranges for forecasts.

Program 1:

```
/* Definition of confidence ranges for forecasts */
/* based on the generalized Goel-Okomoto model */

#include <stdlib.h>
#include <math.h>
#include <stdio.h>

#define true   1
#define false -1

double mv_genGO(double,double,double,double); double poisson(double,long); void ki_nhpp();
int main(argc,argv)
int argc;
char *argv[];
{
double a,b,c,bt,st,kn;
long low,upp,lauf;

if (argc<7) {
printf("\n\nZuwenig Argumente! \n\n");
printf("Aufruf: %s <Par1> <Par2> <Par3> <Startzeit> <Endzeit>",
"<KNiveau>\n\n", argv[0]); return 1;
 }

a = atof(argv[1]);
b = atof(argv[2]);
c = atof(argv[3]);
bt= atof(argv[4]);
st= atof(argv[5]);
kn= atof(argv[6]);

for (lauf=1;lauf< ;lauf++) {
ki_nhpp(mv_genGO,a,b,c,bt,bt+lauf*(st-bt)/10.,kn,&low,&upp);
printf("Zeitpunkt: %8.2f     Fehlerintervall: [%d,%d]\n",
bt+lauf*(st-bt)/10., low, upp);
 }
return 0;
}

double mv_genGO(x,a,b,c)
double x,a,b,c;
{ return( a*(1.0-exp(-b*pow(x,c))) ); }

double poisson(lambda,wert)
double lambda;
long wert;
{
long i;
double itval,hv;

if (lambda<600) {
itval = exp(-lambda);
for (i=wert;i>=1;i--) { itval *= lambda/(double)i; }
 }
```

```
else {
hv = exp(-lambda/(double)wert);
itval = 1.0;
for (i=wert;i>=1;i--) { itval *= lambda/(double)i*hv; }
 }
return ( itval );
}

void ki_nhpp(mv_nhpp, par1_nhpp, par2_nhpp, par3_nhpp,
start_time, stop_time, k_niveau, lower, upper) double mv_nhpp(double,double,double,double);
    double par1_nhpp, par2_nhpp, par3_nhpp, start_time, stop_time, k_niveau; long *lower, *upper;
{
long lauf;
int lborder,mod_low,mod_upp;
double sum,tmp_mv, val_l, val_u;

tmp_mv = mv_nhpp(stop_time,par1_nhpp,par2_nhpp,par3_nhpp) -
mv_nhpp(start_time,par1_nhpp,par2_nhpp,par3_nhpp); lauf = (long)tmp_mv;
*lower = lauf-1;
*upper = lauf+1; mod_low= false; mod_upp= false; sum   = poisson(tmp_mv,lauf); val_l =
    poisson(tmp_mv,*lower); val_u  = poisson(tmp_mv,*upper);
while (sum<k_niveau) {
if (val_l<val_u) {
sum += val_u;
(*upper)++;
lborder = false;
mod_upp = true;
val_u  = poisson(tmp_mv,*upper);
   }
else {
sum += val_l;
(*lower)--;
lborder = true;
mod_low = true;
val_l  = poisson(tmp_mv,*lower);
   }
 }

if (lborder == true) { (*lower)++; }
else             { (*upper)--; }

if (mod_low == false) { (*lower)++; }
if (mod_upp == false) { (*upper)--; }

return;
}
```

Program 2:

/* Simulated definition of confidence ranges for forecasts */
/* based on the generalized Goel-Okomoto model */

```
#include <stdlib.h>
#include <math.h>
#include <time.h>
#include <stdio.h>
#include <values.h>

#define true  1
#define false -1

double drand48(void);
void srand48(long);

double sim_exp(double); double lambda_genGO(double,double,double,double); void sim_nhpp();
int main(argc,argv)
int argc;
char *argv[];
{
time_t t; double a,b,c,bt,st,pnt[1000000],check_time[12]; long lauf,no_pnt,seed_run; int clauf;
FILE *datei;
if (argc<6) {
printf("\n\nZuwenig Argumente! \n\n");
printf("Aufruf: %s <Par1> <Par2> <Par3> <Startzeit> <Endzeit>\n\n",
argv[0]); return 1;
 }

datei = fopen("sim.seed","r");
if (datei==NULL) {
seed_run = 1;
 }
else {
fscanf(datei,"%6d",&seed_run); fclose(datei); seed_run++;
 }

datei = fopen("sim.seed","w+");
fprintf(datei, "%6d\n", seed_run );
fclose(datei);

 time (&t) ;                   /* Initialisierung des      */
 t += seed_run*100 ;           /* Zufallszahlengenerators  */
srand48 ((unsigned long) t) ; /* mit Hilfe der Systemzeit */
a = atof(argv[1]);
b = atof(argv[2]);
c = atof(argv[3]);
bt= atof(argv[4]);
st= atof(argv[5]);

sim_nhpp(lambda_genGO,a,b,c,bt,st,&pnt,&no_pnt);
for (lauf=1;lauf<=no_pnt;lauf++) {
printf("%15.7f %10d \n", pnt[lauf], lauf);
 }
```

```
datei = fopen("ki.tmp","a");
for (lauf=1;lauf< ;lauf++) {
check_time[lauf] = bt+lauf*(st-bt)/10.;
 }
check_time[11] = pnt[no_pnt]+1; /* größer als die größte
simulierte Zeit */
clauf = 1;
for (lauf=1;lauf<=no_pnt;lauf++) {
while (pnt[lauf]>=check_time[clauf]) { fprintf(datei, "%8.2f %6d ", check_time[clauf], lauf-1); clauf++;
  }
 }

if (pnt[no_pnt] <check_time[10]) {
for (lauf=clauf;lauf< ;lauf++) {  fprintf(datei, "%8.2f %6d ", check_time[lauf], no_pnt);
  }
 }

fprintf(datei, "\n");
fclose(datei);

return 0;
}

double sim_exp(lambda)
double lambda;
{ return( -log(drand48())/lambda ); }

double lambda_genGO(x,a,b,c)
double x,a,b,c;
{ return( a*b*c*pow(x,c-1)*exp(-b*pow(x,c)) ); }

void sim_nhpp(lambda_nhpp, par1_nhpp, par2_nhpp, par3_nhpp,
start_time, stop_time, path, no_points) double lambda_nhpp(double,double,double,double); double
    par1_nhpp, par2_nhpp, par3_nhpp, start_time, stop_time; double path[]; long *no_points;
{
double sim_time,x,u,x_bar,lambda_bar;
*no_points=0;
sim_time = start_time;

do {
if (par3_nhpp<=1) { lambda_bar = lambda_nhpp(sim_time,par1_nhpp,par2_nhpp,par3_nhpp);
  }
else {
x_bar = pow((par3_nhpp-1.0)/par2_nhpp/par3_nhpp,1.0/par3_nhpp);
if (sim_time>=x_bar) {
lambda_bar = lambda_nhpp(sim_time,par1_nhpp,par2_nhpp,par3_nhpp);
   }
else {
lambda_bar = lambda_nhpp(x_bar,par1_nhpp,par2_nhpp,par3_nhpp);
   }
  }

x = sim_exp(lambda_bar);
u = drand48();
```

```
if (u<=lambda_nhpp(sim_time+x,par1_nhpp,par2_nhpp,par3_nhpp)/lambda_bar) { (*no_points)++;
    path[*no_points]=sim_time+x;
   }
sim_time+=x;
 }
while (sim_time<=stop_time);
return;
}
```

Program 3:

/* Definition of confidence ranges from the simulation data */
/* (the simulation data is sorted into ascending order) */

```
#include <stdlib.h>
#include <math.h>
#include <stdio.h>

int qsort_icmp(int*,int*);
int qsort_icmp(x,y)
int *x, *y;
{
if (*x<*y)      { return ( -1 ); }
else if (*x==*y) { return (  0 ); }
else            { return (  1 ); }
}

int main(argc,argv)
int argc;
char *argv[];
{
int pnt[11][100000];
int qs[100000];
char *dname;
int frac,i;
long lauf,lower_bound,upper_bound;
long l,no_pnt,seed_run;
double ctime[11],x;
FILE *datei;


if (argc<3) {
printf("\n\nZuwenig Argumente! \n\n"); printf("Aufruf: %s <Dateiname> <Konfidenzniveau (in
    %%)>\n\n", argv[0]); return 1;
 }

dname = argv[1];
frac  = 100-atoi(argv[2]);
lauf = 0;

datei = fopen(dname,"r");
if (datei==NULL) { return 1; }
else {
while (!feof(datei)) {
lauf++;
for (i=1;i<=9;i++) {
fscanf(datei,"%8lf %6d ", &ctime[i],  &pnt[i][lauf]);
    }
fscanf(datei,"%8lf %6d \n", &ctime[10],  &pnt[10][lauf]);
  }
fclose(datei);
 }

lower_bound = (long)floor(lauf*frac/200.); upper_bound = (long)ceil(lauf*(200.-frac)/200.);
if (lower_bound<1) {lower_bound = 1;}
```

```
printf("\n\n%2d%%-Sicherheitsbereich bei %d Simulationsläufen\n\n",
100-frac,lauf);
for (i=1;i< ;i++) {
for (l=1;l<=lauf;l++) {
qs[l] = pnt[i][l];
   }

qsort(&qs[1], lauf, sizeof(int), &qsort_icmp);
printf("Zeitpunkt: %8.2f     Fehlerintervall: [%d,%d]\n",
ctime[i], qs[lower_bound], qs[upper_bound]);
 }

return 0 ;
}
```

References:

[1] Sidney I. Resnick: "Adventures in Stochastic Processes", Birkhäuser Boston, 1992, ISBN 3-7643-3591-2, pp. 303-317

[2] Brately et al., 1987

Patent claims

1. A method for predicting measurement data until a final time-point using given measurement data, in which:
   a) a stochastic process is matched to the given measurement data;
   b) simulation runs of the stochastic process are carried out from a given time-point until the final time-point;
   c) the forecast measurement data is determined for each simulation run;
   d) measurement data is predicted by stating a range of values, which is determined by the forecast measurement data.

2. The method as claimed in claim 1, in which: a confidence range is determined for the prediction of measurement data, where the a% lowest and b% highest forecast measurement data are eliminated.

3. The method as claimed in claim 2, in which: a% and b% are equal.

4. The method as claimed in one of the preceding claims, in which: the stochastic process is a non-homogeneous Poisson process.

5. The method as claimed in one of the preceding claims, in which: the measurement data represents numbers of errors.

6. The method for predicting measurement data using given measurement data, in which:
   a) a stochastic process is matched to the given measurement data;

b) a range is ascertained, by sorting the probability values generated by the

stochastic process according to size, around an expected value;

c) measurement data is predicted within the limits of the range.

7. The method as claimed in claim 6, in which: the probability values generated by the stochastic process are sorted symmetrically by size around the expected value.

8. An arrangement for predicting measurement data until a final time-point using given measurement data, whereby a processor unit is provided and configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) simulation runs of the stochastic process can be carried out from a given time-point until the final time-point;

c) the forecast measurement data can be determined for each simulation run;

d) measurement data is predicted by stating a range of values, which is determined by the forecast measurement data.

9. An arrangement for predicting measurement data using given measurement data, whereby a processor unit is provided and configured in such a way that:

a) a stochastic process can be matched to the given measurement data;

b) a range can be ascertained by sorting probability values generated by the stochastic process according to size around an expected value;

c) the measurement data is predicted within the limits of the range.

GR 98 P 5929

Abstract

Method and arrangement for predicting measurement data using given measurement data

A method and an arrangement are proposed for predicting measurement data using given measurement data, in which a stochastic process is matched to the given measurement data. Simulation runs are carried out from a given time-point until a final time-point. The forecast measurement data is determined for each simulation run. Measurement data for the final time-point is predicted within a range of values, which is determined by the forecast measurement data.

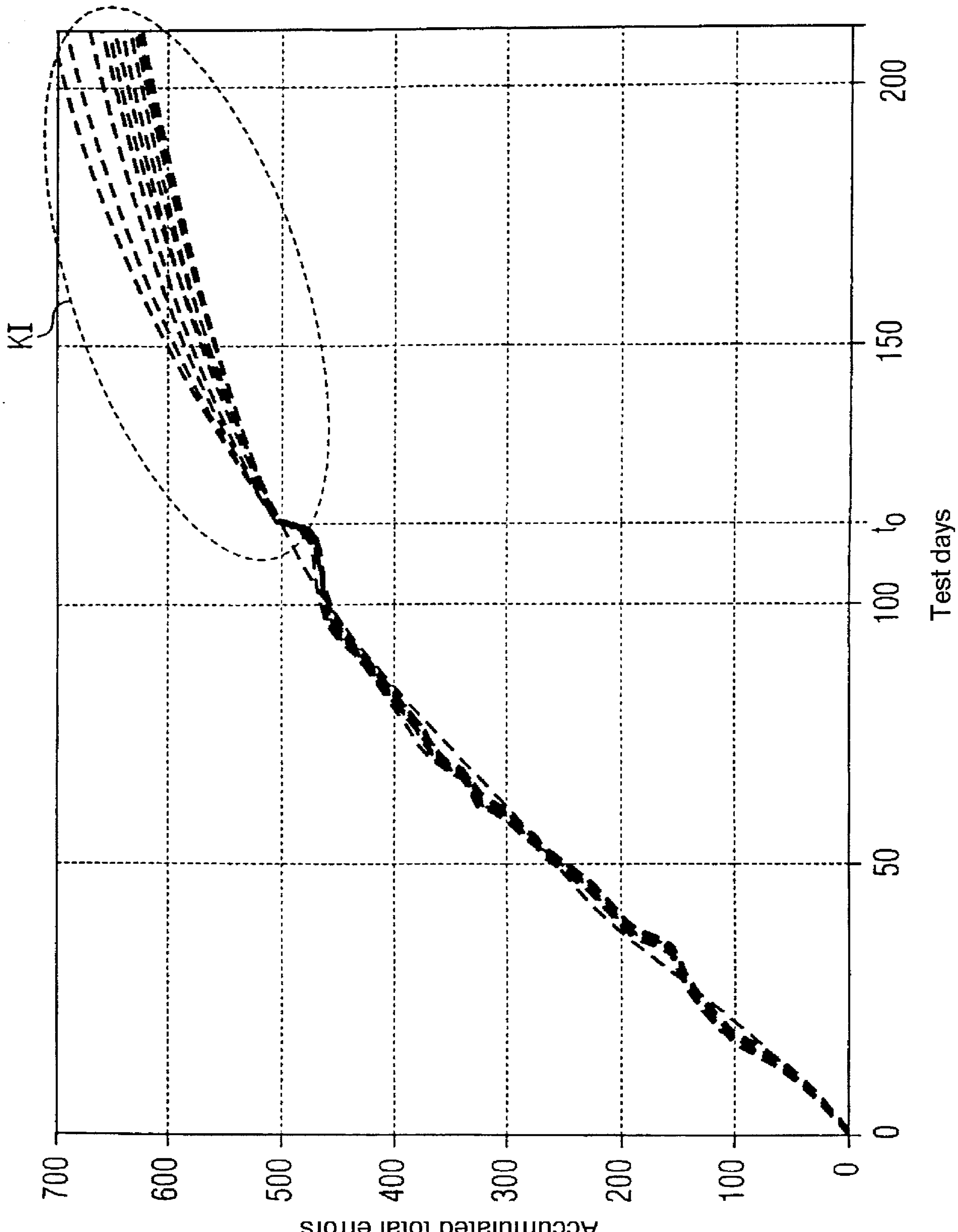

KI
Accumulated total errors
700
600
500
400
300
200
100
0
0
50
100
t_0
150
200
Test days

FIG 1

FIG 2

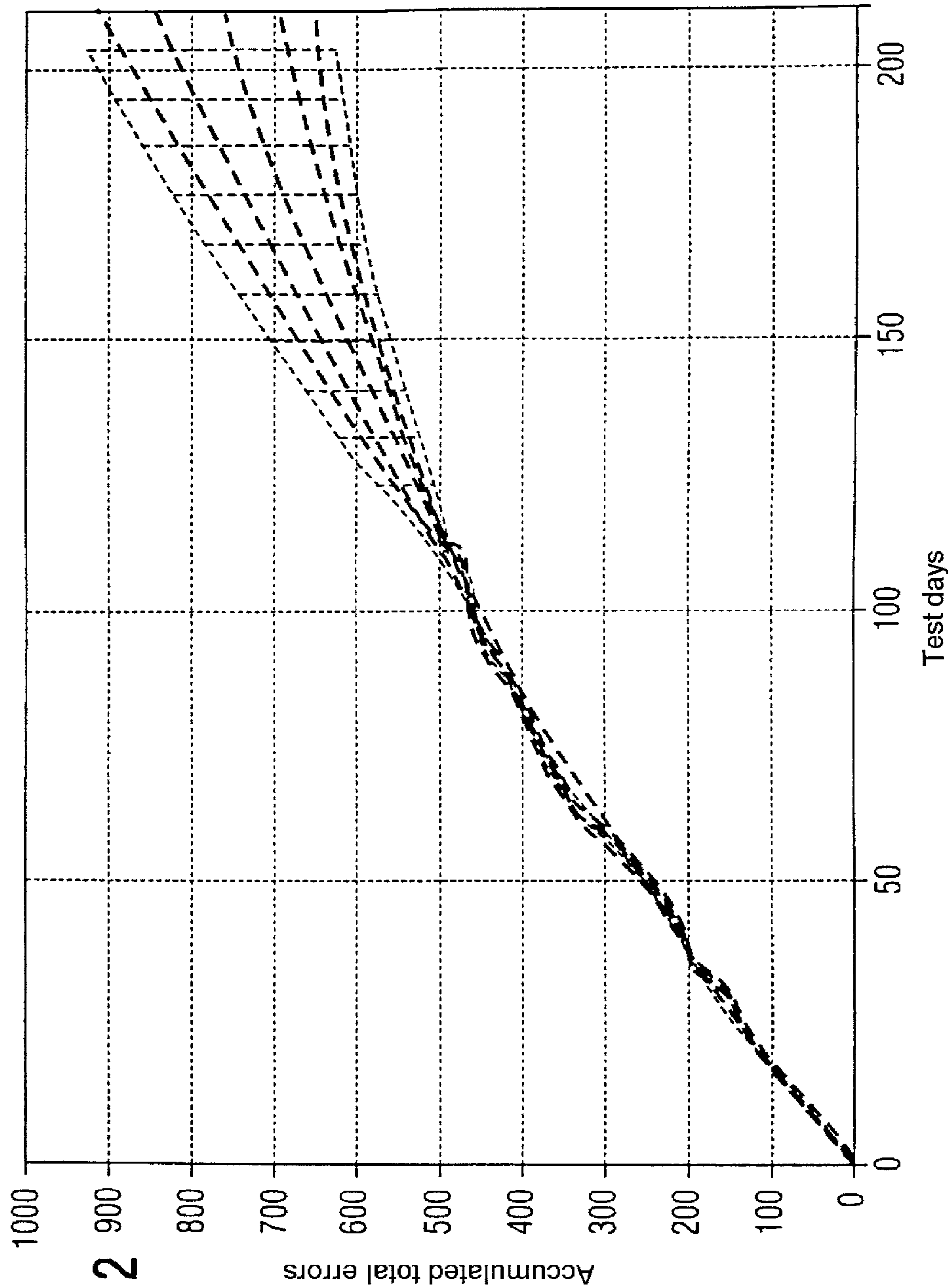

Accumulated total errors
0
100
200
300
400
500
600
700
800
900
1000
Test days
0
50
100
150
200

FIG 3

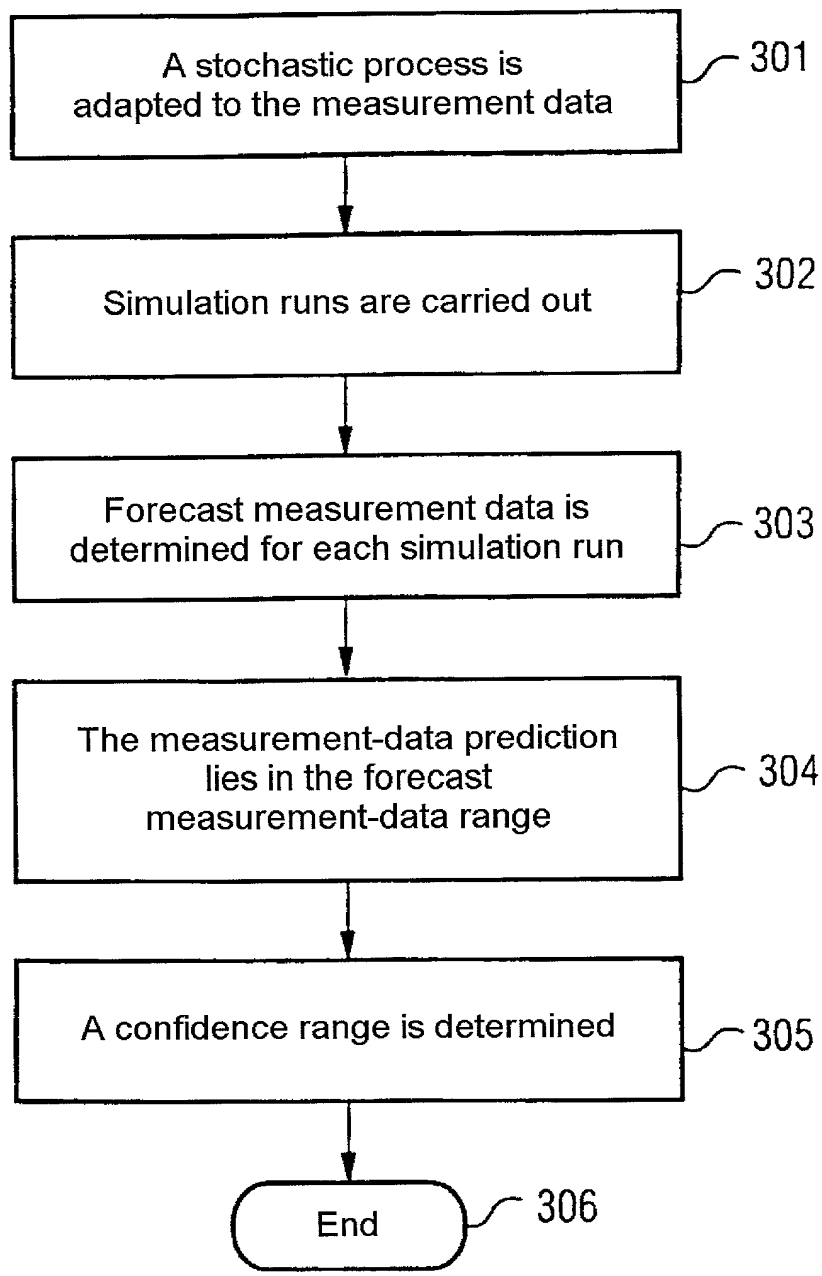

A stochastic process is adapted to the measurement data
301
Simulation runs are carried out
302
Forecast measurement data is determined for each simulation run
303
The measurement-data prediction lies in the forecast measurement-data range
304
A confidence range is determined
305
End
306

FIG 4

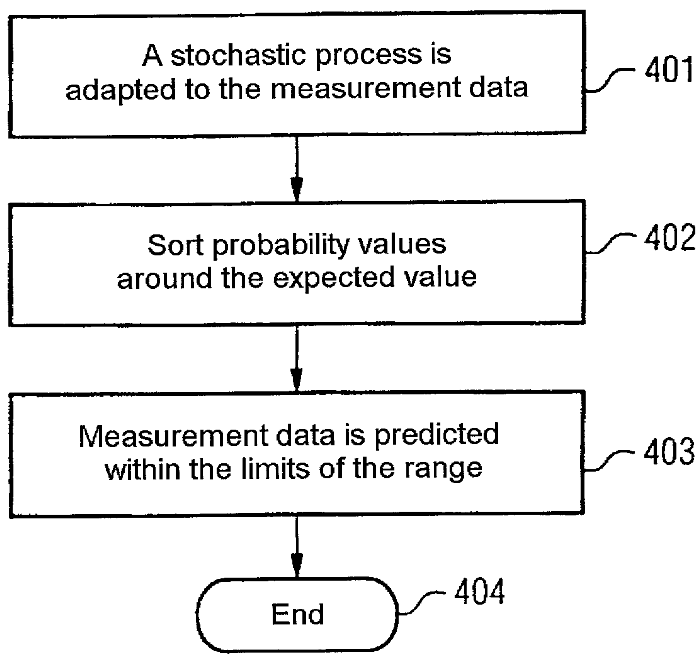
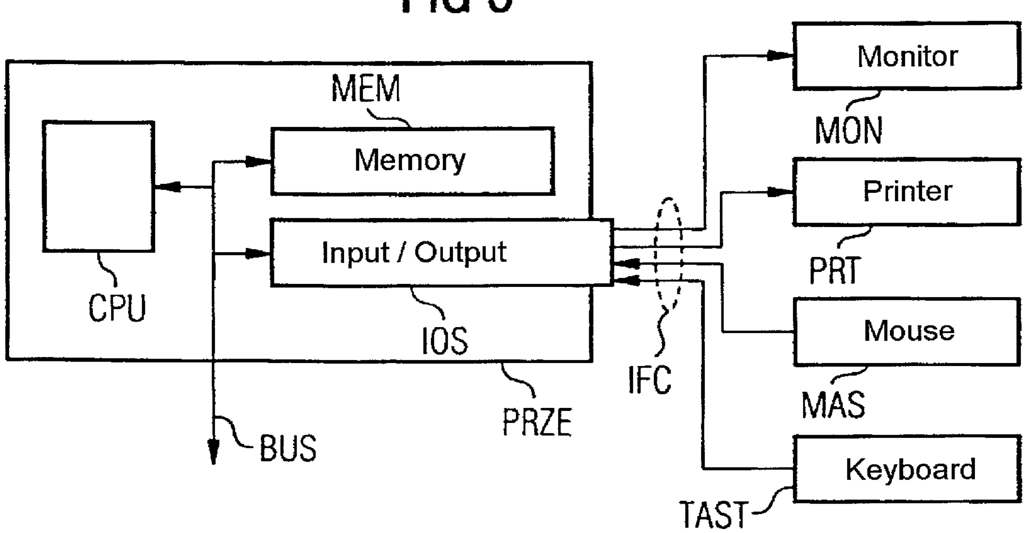

A stochastic process is adapted to the measurement data
401
Sort probability values around the expected value
402
Measurement data is predicted within the limits of the range
403
End
404

FIG 5


MEM
Memory
Input / Output
CPU
IOS
PRZE
BUS
IFC
Monitor
MON
Printer
PRT
Mouse
MAS
Keyboard
TAST

Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

As a below named inventor, I hereby declare that:

dass mein Wohnsitz, meine Postanschrift, und meine Staatsangehörigkeit den im Nachstehenden nach meinem Namen aufgeführten Angaben entsprechen,

My residence, post office address and citizenship are as stated below next to my name,

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

VERFAHREN UND ANORDNUNG ZUR VORHERSAGE VON MESSDATEN ANHAND VORGEGEBENER MESSDATEN

METHOD AND ARRANGEMENT FOR PREDICTING MEASUREMENT DATA BY MEANS OF GIVEN MEASUREMENT DATA

deren Beschreibung

(zutreffendes ankreuzen)
☐ hier beigefügt ist.
☒ am 10.12.1999 als
PCT internationale Anmeldung
PCT Anmeldungsnummer PCT/DE99/03955
eingereicht wurde und am ______
abgeändert wurde (falls tatsächlich abgeändert).

the specification of which

(check one)
☐ is attached hereto.
☒ was filed on 10.12.1999 as
PCT international application
PCT Application No. PCT/DE99/03955
and was amended on ______
(if applicable)

Ich bestätige hiermit, dass ich den Inhalt der obigen Patentanmeldung einschliesslich der Ansprüche durchgesehen und verstanden habe, die eventuell durch einen Zusatzantrag wie oben erwähnt abgeändert wurde.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

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I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

IDNR: 2590 / V: 99-1.00 / B:Val

German Language Declaration

Prior foreign appplications
Priorität beansprucht

Priority Claimed

19858093.2	DE	16.12.1998	☒ Yes / Ja	☐ No / Nein
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)		
			☐ Yes / Ja	☐ No / Nein
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)		
			☐ Yes / Ja	☐ No / Nein
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)		

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

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PCT/DE99/03955	10.12.1999		
(Application Serial No.) (Anmeldeseriennummer)	(Filing Date D, M, Y) (Anmeldedatum T, M, J)	(Status) (patentiert, anhängig, aufgegeben)	(Status) (patented, pending, abandoned)
(Application Serial No.) (Anmeldeseriennummer)	(Filing Date D,M,Y) (Anmeldedatum T, M; J)	(Status) (patentiert, anhängig, aufgeben)	(Status) (patented, pending, abandoned)

Ich erkläre hiermit, dass alle von mir in der vorliegenden Erklärung gemachten Angaben nach meinem besten Wissen und Gewissen der vollen Wahrheit entsprechen, und dass ich diese eidesstattliche Erklärung in Kenntnis dessen abgebe, dass wissentlich und vorsätzlich falsche Angaben gemäss Paragraph 1001, Absatz 18 der Zivilprozessordnung der Vereinigten Staaten von Amerika mit Geldstrafe belegt und/oder Gefängnis bestraft werden koennen, und dass derartig wissentlich und vorsätzlich falsche Angaben die Gültigkeit der vorliegenden Patentanmeldung oder eines darauf erteilten Patentes gefährden können.

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German Language Declaration

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And I hereby appoint

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6600 Sears Tower 60606-6473 Chicago, Illinois
Telephone: +1 312 258 5780 and Facsimile +1 312 258 5921
or
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1-00

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91074 HERZOGENAURACH	91074 HERZOGENAURACH

2-00

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Unterschrift des Erfinders: Michael Greiner / Datum: 21.5.01	Second Inventor's signature / Date
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Staatsangehörigkeit: DE	Citizenship: DE
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85221 DACHAU	85221 DACHAU

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).

3-60

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Staatsangehörigkeit: DE	Citizenship: DE
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14469 Potsdam	14469 Potsdam

4-60

Voller Name des vierten Miterfinders:	Full name of fourth joint inventor:
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Unterschrift des Erfinders / Datum: 21.5.2001	Inventor's signature / Date
Wohnsitz: MUENCHEN, DEUTSCHLAND DEX	Residence: MUENCHEN, GERMANY DEX
Staatsangehörigkeit: DE	Citizenship: DE .
Postanschrift: SALMDORFER STR. 5	Post Office Address: SALMDORFER STR. 5
81929 MUENCHEN	81929 MUENCHEN

Voller Name des fünften Miterfinders:	Full name of fifth joint inventor:
Unterschrift des Erfinders / Datum	Inventor's signature / Date
Wohnsitz: ,	Residence: ,
Staatsangehörigkeit	Citizenship
Postanschrift	Post Office Address

Voller Name des sechsten Miterfinders:	Full name of sixth joint inventor:
Unterschrift des Erfinders / Datum	Inventor's signature / Date
Wohnsitz: ,	Residence: ,
Staatsangehörigkeit	Citizenship
Postanschrift	Post Office Address

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).